Lunar Reconnaissance Orbiter
Lunar Orbiter Laser Altimeter
Archive Volume
Software Interface Specification

Version 2.1

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SIGNATURE PAGE

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TABLES AND FIGURES

DOCUMENT CHANGE LOG

Change	Date	Affected Portions
Ward's suggested changes adopted, red text gone.	3/24/08	acronyms, all sections
Revisions by S. Slavney	5/19/08	1.2, 1.3, 2.3, 2.4, 2.5, 2.7, 2.9, 3.1.3, 4.1, 4.2, 4.4, 4.5 revised. BROWSE and EXTRAS directory sections deleted.
Revisions to product descriptions	8/14/08	3.16
Added BROWSE description	10/22/08	2.10
Added description of Index table columns	10/26/08	2.3, 6
Added Signature Page	10/26/08	ii
Version updated to October 22, 2008 Version 2	10/26/08	1.3
Section 2.1, second sentence, “are”, removed	10/26/08	2.1
Section 2.11, ISO 9660 standards conformance	10/26/08	2.11
Additions to Applicable Documents	10/26/08	1.3, 3.1.3
Volume ID clarified	10/26/08	4.5
Reference radius choices clarified	10/26/08	3.1.6
Table headings added	10/26/08	all
Table entries are punctuated if sentences.	10/26/08	all
Column for resolution date added to TBD items	11/17/08	v
Description of the PDS NAIF Node and SPICE	11/17/08	vi, 2.9
Figures 1 and 2 - DEM subdivisions added	11/17/08	3.1.6
Index table column descriptions clarified	11/17/08	6.1
Explanation of relationships with radio science	11/17/08	1.4

TBD ITEMS

Section	Description	Resolution Date
3	Use of JPEG2000 format for GDR products	Launch + 6 months

ACRONYMS AND ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
DVD-ROM	Compact Disk or Digital Video Disk - Read-Only Memory
EDR	Experiment Data Record
GDR	Gridded Data Record, as elevation with respect to a sphere
GSFC	Goddard Space Flight Center
HTML	HyperText Markup Language
ILRS	International Laser Ranging Service
ISO	International Standards Organization 9660/UDF standards
JPEG	Joint Photographic Experts Group image format
JPL	Jet Propulsion Laboratory
LOLA	Lunar Orbiter Laser Altimeter
LRO	Lunar Reconnaissance Orbiter
NAIF	Navigation and Ancillary Information Facility of the PDS
NSSDC	National Space Science Data Center
PDF	Portable Document Format
PDS	Planetary Data System
PNG	Portable Network Graphics image format
RDR	Reduced Data Record
SHADR	Spherical Harmonic Data Record
SIS	Software Interface Specification
SOC	Science Operations Center
TBD	To Be Determined
UTC	Coordinated Universal Time

GLOSSARY

Archive – An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

Archive Volume, Archive Volume Set – A volume is a unit of media on which data products are stored; for example, one DVD-ROM. An *archive volume* is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an *archive volume set*. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.

Catalog Information – Descriptive information about a data set (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) which is suitable for loading into a PDS catalog.

Data Product – A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.

Data Set – An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

Digital Elevation Model – A raster map of height with respect to lunar center of mass. The elevation may be shape values (absolute radii) or relative to a sphere of constant radius.

SPICE – An information system to assist scientists in planning and interpreting scientific observations from space-based instruments, maintained by the PDS NAIF Node.

Standard Data Product – A data product generated in a predefined way using well-understood procedures, processed in "pipeline" fashion. Data products that are generated in a nonstandard way are sometimes called *special data products*.

1. Introduction

1.1. Purpose and Scope

This Software Interface Specification is intended to be used by those who wish to understand the format and content of the Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA) Archive. Typically, these individuals would be software engineers, data analysts, or planetary scientists.

The specifications in this document apply to all LOLA standard product archive volumes that are generated by the LRO Project.

Table 1. LOLA standard Data Product Datasets

Product Type	Data Set ID	Description
LOLA_EDR	LRO-L-LOLA-2-EDR-V1.0	Raw altimetry data
LOLA_RDR	LRO-L-LOLA-3-RDR-V1.0	Calibrated altimetry data
LOLA_GDR	LRO-L-LOLA-4-GDR-V1.0	Gridded (raster) digital elevation and related models
LOLA_SHADR	LRO-L-LOLA-5-SHADR-V1.0	Spherical harmonics gravity/topography models

1.2. Content Overview

This Software Interface Specification (SIS) describes the format, content, and generation of the LRO LOLA Instrument Data Archive. The Archive Volume will be comprised of raw telemetry data, when they are collected, and calibrated, reduced and resampled data, when they are processed. Some of the data will be reprocessed with higher accuracy during the course of the LRO mission, and the updated versions will logically supercede earlier versions. Such data will include gridded data and spherical harmonic models, each of which will be based on the accumulated data as of the close of their production cycle, approximately monthly. LOLA data products are generated by the LOLA Science Operations Center (SOC) at GSFC. Section 2, Archive Volume Generation, describes the procedure for transferring data products to archive media. Section 3, Archive Volume Contents, describes the structure of the archive volumes and the contents of each file. Section 4, Archive Volume Format, describes the file formats used on the archive volumes. Finally, Section 5, Support Staff and Cognizant Persons, lists the individuals responsible for generating the archive volumes.

1.3. Applicable Documents and Constraints

This Archive Volume SIS is intended to be consistent with the following documents:

1. Lunar Reconnaissance Orbiter Project Data Management and Archive Plan, 431-PLAN-00182.
2. Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter Experiment Data Record Software Interface Specification (LOLA EDRSIS) V.2, October 26, 2008.
3. LOLA Science Operations Center Requirements Document, Revision B, October 25, 2006.

4. LOLA Instrument Team Data Management and Archive Plan, Aug. 31, 2006.
5. Memorandum of Agreement for Establishment of the LRO LOLA Data Node Between the PDS Geosciences Node, Washington University, St. Louis, Missouri, and the Lunar Reconnaissance Orbiter (LRO) LOLA Instrument Team, Goddard Space Flight Center, Greenbelt, Maryland, October 27, 2006.
6. LRO LOLA Science Team and PDS Geosciences Node ICD, October 9, 2006.
7. *Planetary Data System Archive Preparation Guide*, August 29, 2006, Version 1.1, JPL D-31224.
8. *Planetary Data System Standards Reference*, March 20, 2006, Version 3.7. JPL D-7669, Part 2.
9. ISO 9660-1988, Information Processing - Volume and File Structure of CD-ROM for Information Exchange, April 15, 1988.
10. *A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter*, LRO Project White Paper, 451-SCI-000958, Version 3, January 30, 2008.
11. Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter Experiment Data Record Software Interface Specification (EDRSIS), V2, October 26, 2008.
12. Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter Reduced Data Record and Derived Products Software Interface Specification (RDRSIS), V2.1, November 17, 2008 .

1.4. Relationships with Other Interfaces

The LOLA instrument is a component of the Laser Ranging system on board LRO. This Archive Volume SIS could be affected by changes to the design of the International Laser Ranging Service (ILRS) and LRO Data Management System. The LRO radio tracking data are generated by the LRO Ground Data System, but there is no formal Radio Science investigation. These data are received by the LOLA Science Operations Center but they are being archived separately from the LOLA Measurement Investigation. The Laser Ranging data will be added to this archive when it is available, but will also be maintained by the ILRS through the Crustal Dynamics Data Information System.

2. Archive Volume Contents

This section describes the contents of the LOLA Archive volumes, including the file names, file contents, file types, and organization responsible for providing the files.

2.1. Root Directory Contents

Files in the Root Directory include an overview of the archive, a description of the volume for the PDS Catalog, and a list of errata or comments about the archive. The following files and directories are contained in the Root Directory.

Table 2. Description of files in ROOT Directory

File Name	File Contents	File Provided By
AAREADME.TXT	Volume content and format information	LOLA Instrument Team

ERRATA.TXT	A cumulative listing of comments and updates concerning all archive volumes published to date	LOLA SOC
VOLDESC.CAT	A description of the contents of this volume in a PDS format readable by both humans and computers	LOLA SOC
/BROWSE	Images and hypertext files related to DATA	LOLA SOC
/CATALOG	Descriptions of data set, instruments, spacecraft, and mission as found in the PDS Catalog	LOLA SOC and Geosciences
/CALIB	Calibration documents, tables, notes	LOLA SOC
/DATA	Directories for standard product types	LOLA SOC
/DOCUMENT	Software interface specification files and labels	LOLA SOC
/EXTRAS	Tools and useful “value-added” context material, not crucial to understanding the dataset	LOLA SOC
/GEOMETRY	Instrument orientation with respect to spacecraft and lunar reference system	LOLA SOC
/INDEX	Files provided to help the user locate products on this archive volume and on previously released volumes in the archive	Geosciences
/LABEL	Descriptions of data file formats, referenced by PDS labels	LOLA SOC
/SOFTWARE	Source code library to aid programmers in parsing the data files	LOLA SOC

2.2. Data Directory Contents and Naming

Under the Data directory there is a separate subdirectory for each type of product. The subdirectories may include one or more of the following: LOLA_EDR, LOLA_RDR, LOLA_GDR, LOLA_SHADR. The EDR is the data produced by the instrument, in a form as close as possible to the files recorded on the spacecraft. The RDR is calibrated, edited, and geolocated data at the original density. The GDR is a resampled, gridded dataset, in cylindrical and polar projections. The SHADR is a set of spherical harmonic coefficients describing the lunar shape, selenopotential reference surface, albedo, and static gravitational potential. The LOLA_EDR directory is further divided into subdirectories named LRO_PP_NN, where PP refers to the first two letters of mission phase (CO = Commissioning, NO = Nominal, EX = Extended), and NN refers to the current monthly orbital cycle, ending with Station Keeping Maneuvers. Subdirectories of the monthly directories, one per Coordinated Universal Time (UTC) day, will contain the individual EDR products. A subdirectory name shall be of the form YYYYDDD. Typical filepaths for the EDR product will be

/DATA/LOLA_EDR/LRO_NO_NN/YYYYDDD/LOLAEDR_YYDDDHHMM.DAT.

Typical file paths for the RDR product will be

/DATA/LOLA_RDR/LRO_NO_NN/LOLARDR_rrrrrx.DAT,

where rrrrr refers to the orbit number and x refers to the lunar hemisphere, either N or S.

This schematic shows an example of the nesting of directories for the EDR volume for data acquired beginning at midnight March 18, 2009 through March 19 2009.

<Volume Root>

DATA|

| LOLA_EDR

| | LRO_NO_03

| | | 2009078

| | | | <LOLAEDR_09078hhmm.DAT files>

...

This schematic shows an example of the nesting of directories for the RDR/GDR/SHADR volume/

<Volume Root>

DATA|

|LOLA_GDR

| | <LDEM_nnn[<tilespecs>].IMG files>

|LOLA_RDR

| | LRO_NO_03

| | |<LOLARDR_rrrrrx.DAT files>

|LOLA_SHADR

| <LOLA Spherical harmonic models and constants>

2.3. Index Directory Contents

Files in the Index Directory are provided to help the user locate products on this archive volume and on previously released volumes in the archive. The INDEX.TAB file consists of an INDEX_TABLE object. The INDEX.TAB file contains 14 columns described in the INDEX.LBL file. An example of the INDEX.LBL file may be found in Appendix 6.1. CUMINDEX.LBL and CUMINDEX.TAB describe the accumulated volumes from current and previous releases. The following files are contained in the Index Directory.

Table 3. Description of files in LABEL Directory

File Name	File Contents	File Provided By
CUMINDEX.LBL	A PDS detached label that describes CUMINDEX.TAB	LOLA SOC
CUMINDEX.TAB	A cumulative listing of all data products on this volume and on previous volumes in this set (only for data sets with multiple volumes)	LOLA SOC
INDEX.LBL	A PDS detached label that describes INDEX.TAB	LOLA SOC
INDEX.TAB	A table listing all data products on this volume	LOLA SOC
INDXINFO.TXT	A description of the contents of this directory	LOLA SOC

2.4. Document Directory Contents

The Document Directory contains documentation to help the user understand and use the archive data. The following files are contained in the Document Directory.

Table 4. Description of files in DOCUMENT Directory

File Name	File Contents	File Provided By
DOCINFO.TXT	A description of the contents of this directory	LOLA SOC
EDRSIS.HTM	The EDR Data Product SIS as hypertext	LOLA SOC
EDRSIS.PDF	The EDR Data Product SIS as a PDF file	LOLA SOC
EDRSIS.LBL	A detached label that describes both EDRSIS.HTM and EDRSIS.PDF	LOLA SOC
RDRSIS.HTM	The RDR Data Product SIS as hypertext	LOLA SOC
RDRSIS.PDF	The RDR Data Product SIS as a pdf file	LOLA SOC
RDRSIS.LBL	A detached label that describes both RDRSIS.HTM and RDRSIS.PDF	LOLA SOC
GDRSIS.HTM	The GDR Data Product SIS as hypertext	LOLA SOC
GDRSIS.PDF	The GDR Data Product SIS as a pdf file	LOLA SOC
GDRSIS.LBL	A detached label that describes both GDRSIS.HTM and GDRSIS.PDF	LOLA SOC
ARCHSIS.HTM	The Archive Volume SIS (this document) as hypertext	LOLA SOC
ARCHSIS.PDF	The Archive Volume SIS (this document) as a PDF file	LOLA SOC
ARCHSIS.LBL	A PDS detached label that describes both ARCHSIS.HTM and ARCHSIS.PDF.	LOLA SOC
PDSDD.FUL	A file that identifies and describes the data object and data element definitions	LOLA SOC
PDSDD.IDX	An index of the PDSDD.FUL used by the PDS validation tools	LOLA SOC
PDSDD.LBL	A PDS detached label that describes the PDSDD.FUL	LOLA SOC

2.5. Catalog Directory Contents

The files in the Catalog Directory provide a top-level understanding of the mission, spacecraft, instruments, and data sets. The files in this directory are coordinated with the PDS data engineer, who is responsible for loading them into the PDS catalog. The following files are found in the Catalog Directory.

Table 5. Description of files in CATALOG Directory

File Name	File Contents	File Provided By
CATINFO.TXT	A description of the contents of this directory	LOLA SOC
EDR_DS.CAT	EDR data set information for the PDS catalog	LOLA SOC
RDR_DS.CAT	RDR dataset information for the PDS	LOLA SOC
GDR_DS.CAT	Gridded Data Record information for the PDS	LOLA SOC
SHADR_DS.CAT	Spherical Harmonic Data Record information for the PDS	LOLA SOC
INSTHOST.CAT	Instrument host (i.e., spacecraft) information for the PDS catalog	LRO Project

LOLAINST.CAT	Instrument information for the PDS catalog	LOLA SOC
MISSION.CAT	Mission information for the PDS catalog	LRO Project
PERSON.CAT	Personnel information for the PDS catalog (Team and PDS personnel responsible for generating the archive)	LOLA SOC
REF.CAT	References mentioned in other *.CAT files	LOLA SOC

2.6. Label Directory Contents

The Label Directory contains files that describe data format and organization. These files are referred to in the PDS labels that accompany the data products. They are "include" files that are intended to be parsed as if they were part of the PDS labels that refer to them. The following files are contained in the Label Directory. Level 4 data products will be supplied as a small number of binary images with self-contained detached labels, while Level 5 products will be supplied as text files with attached labels.

Table 6. Description of files in LABEL Directory

File Name	File Contents	File Provided By
LABINFO.TXT	A description of the contents of this directory	LOLA SOC
LOLAEDR.FMT	LOLA science telemetry 1-Hz data format	LOLA SOC
LOLASCCT.FMT	LOLA science telemetry container for 28 Hz data	LOLA SOC
LOLAHKCT.FMT	LOLA housekeeping telemetry container for 28 Hz data	LOLA SOC
LOLARDR.FMT	LOLA reduced science data record format for 28 Hz data	LOLA SOC

2.7. Software Directory Contents

The Software Directory contains utilities or application programs to aid the user in viewing or extracting data from the data product files. Software will be provided at a future date, if necessary for reading the data on various platforms. The PDS label contains the definitive data definitions, particularly for the EDR, and should be referred to first by those who wish to examine the Level 2 data archive. Software that reads the RDR and higher level data products will be more informative for the end users and will be described in applicable document #11.

Table 7. Description of files in SOFTWARE Directory

File Name	File Contents	File Provided By
SOFTINFO.TXT	A description of the contents of this directory	LOLA SOC
SOFTINFO.HTM	HTML version of software	

2.8. Calib Directory Contents

The Calib Directory contains calibration files used to process the data products, or calibration data needed to use the data products. The following files are contained in the Calib Directory.

Table 8. Description of files in CALIB Directory

File Name	File Contents	File Provided By
CALINFO.TXT	A description of the contents of this directory	LOLA SOC

CALIBRPT.LBL	A PDS detached label that describes both CALIBRPT.HTM and CALIBRPT.PDF	
CALIBRPT.PDF	Description of instrument and data calibration performed by LOLA team	LOLA SOC
CALIBRPT.HTM	HTML version of instrument and data calibration	LOLA SOC

There is no calibration information being provided at this time, as the calibration paper has not yet been finished.

2.9. Geometry Directory Contents

The Geometry Directory contains files needed to understand observation geometry. The following files are contained in the Geometry Directory. The PDS Navigation and Ancillary Information Facility (NAIF) provides NASA planetary flight projects and NASA funded professional planetary researchers an information system named "SPICE" to assist scientists in planning and interpreting scientific observations from space-based instruments. SPICE is also widely used in engineering tasks associated with planetary missions. The geometry information will be provided in a format compatible with SPICE Toolkit Version N0062, March 5, 2008, or higher.

Table 9. Description of files in GEOMETRY Directory

File Name	File Contents	File Provided By
GEOMINFO.TXT	A description of the contents of this directory	LOLA SOC
LOLA _NNN.IK	Description of instrument frames used by SPICE	LOLA SOC

Geometry information incorporating refined analyses of the instrument and spacecraft geometry may be produced in CK, SPK, and SCLK formats if funds for this work become available. The C-kernel (CK) system is the component of SPICE concerned with attitude of spacecraft structures or instruments. The SPK system is the component of SPICE concerned with ephemeris data. The SCLK system is the component of SPICE concerned with spacecraft clock correlation data. These will be archived separately via the NAIF Node.

2.10. Browse Directory Contents

The Browse Directory contains reduced-size, easily viewed versions of data products to be used to help identify products of interest. The following files are contained in the Browse Directory.

Table 10. Description of files in BROWSE directory

File Name	File Contents	File Provided By
BROWINFO.TXT	A description of the contents of this directory	LOLA SOC
BROWINFO.HTM	HTML File linking browse images to products	LOLA SOC

The browse information will consist of images of profiles for the EDR and RDR data products, while the GDR products will be thumbnail images of topographic shaded relief or ancillary data. Either PNG or JPEG formats will be employed, with images linked to an HTML-based table.

2.11. Extras Directory Contents

The Extras Directory contains documentation, utility programs, or other materials that the user may find helpful, but that are beyond the scope of the required elements of the archive. There are no restrictions on the contents and organization of this directory other than conformance to ISO-9660/UDF standards. The Extras Directory is intended for "value-added" material, handy to have but not crucial for understanding the data. The following files are contained in the Extras Directory.

Table 11. Description of files in EXTRAS directory

File Name	File Contents	File Provided By
EXTRINFO.TXT	A description of the contents of this directory	LOLA SOC
EXTRINFO.HTM	HTML File linking ancillary documentation and utilities	LOLA SOC

3. Archive Volume Format

This section describes the format of LOLA Archive Volumes. Data that comprise the Archive will be formatted in accordance with Planetary Data System specifications [Applicable Document 8].

3.1. File Formats

This section describes file formats for the kinds of files contained on Archive Volumes.

3.1.1. Document File Format

Document files with the .CAT or .TXT suffix exist in the Root, Index, Software, Catalog, Document, and Label directories. They are ASCII files that may have embedded PDS labels. Lines in such files end with a carriage return character (ASCII 13) and a line feed character (ASCII 10). This allows the files to be readable under various operating systems.

Documents in the Document and Calib directory may contain formatting and figures that cannot be rendered as ASCII text. Therefore each document is given in two formats, hypertext and PDF. The hypertext file contains ASCII text plus hypertext markup language (HTML) commands that enable it to be viewed in a Web browser such as Mozilla (the successor to Mosaic and Netscape), Safari (the default browser for Mac OS), or IE7 (the default browser for Microsoft Corporation products). The hypertext file may be accompanied by ancillary files such as images and style sheets that are incorporated into the document by the Web browser for the convenience of the user. The second format, PDF (Portable Document Format) is a proprietary format of Adobe Systems Incorporated that is frequently used for distributing documents. Adobe offers free software, Acrobat Reader, for viewing PDF files.

3.1.2. Tabular File Format

Tabular files (.TAB suffix) exist in the Index directory. Tabular files are ASCII files formatted for direct reading into many database management systems on various computers. All fields are separated by commas, and character fields are enclosed in double quotation marks ("). (Character fields are padded with spaces to keep quotation marks in the same columns of successive records.) Character fields are left justified, and numeric fields are right justified. The "start byte" and "bytes" values listed in the labels do not include the commas between fields or the quotation marks surrounding character fields. The records are of fixed length, and the last two bytes of each record contain the ASCII carriage return and line feed characters. This allows a table to be treated as a fixed length record file on computers that support this file type and as a text file with embedded line delimiters on those that don't.

All tabular files are described by PDS labels, either embedded at the beginning of the file or detached. If detached, the PDS label file has the same name as the data file it describes, with the extension .LBL; for example, the file INDEX.TAB is accompanied by the detached label file INDEX.LBL in the same directory.

3.1.3. PDS Label Format

All data files in the archive have PDS labels, either embedded at the beginning of the file or, in the case of the EDR data product, detached in a separate file. For examples of PDS labels for each type of data product, see the Data Product SISs [Applicable Documents 2, 11, and 12].

A PDS label, whether embedded or detached from its associated file, consists of lines of ASCII text in the form of keyword = value statements that provide descriptive information about the data file. The label is intended to be readable both by humans and by software. Details of the syntax and semantics of PDS labels can be found in the PDS Standards Reference (Applicable Document 8), and definitions of the keywords used in the label can be found by using the PDS Data Dictionary Lookup web service at

http://pds.jpl.nasa.gov/tools/data_dictionary_lookup.cfm.

Lines of text in detached labels end with a carriage return character (ASCII 13) and a line feed character (ASCII 10). This allows the files to be read under various operating systems.

3.1.4. Software File Format

Files are in the form of text source code, with detached labels. Executable software for commonly used platforms to read binary tables and output ASCII Comma-delimited Values (spreadsheets) will be distributed online at the PDS Geosciences Node.

3.1.5. Catalog File Format

Catalog files (suffix .CAT) exist in the Root and Catalog directories. Like PDS labels, they are text files formatted as keyword = value statements. They contain descriptions of the data set, instrument, spacecraft, and mission, as well as personnel contact information and references to published literature. They are called Catalog Files because they are loaded into the PDS online catalog to make the information available to users searching for data.

3.1.6. Science Data File Formats

The LOLA EDR data products are in the form of binary time-ordered tables representing engineering telemetry and laser time-of-flight data in counts. Each file corresponds to a single file downloaded from the spacecraft solid-state recorder. The binary tables include columns with multi-byte integers in both most-significant-byte-first and least-significant-byte-first order, as well as nonstandard triplets representing 24-bit integers. One file contains approximately 5 minutes of engineering and science data, including Earth ranges from the Laser Ranging experiment. Information about the format and content of the data products is given in the EDR Data Product SIS [Applicable Document 2].

The LOLA RDR data products are maintained in the form of binary time-ordered tables for ease of manipulation, but may be translated into ASCII tables for the end users by means of provided software. Each RDR product will be aggregated on orbital boundaries into a product name with extension ".DAT" and provided with a detached label with the same product name and an extension ".LBL". The detached label will reference Format files contained in the archive's LABEL directory.

The LOLA GDR data products will consist of raster Digital Elevation Models (shape models) as binary images with detached labels. The file type of the GDR products is "IMG". The PDS has also approved the JPEG2000 lossless compressed file standard with a file extension of "JP2". This format may provide better compression and access. Its adoption by LOLA is under review. A pixel will represent the mean value at the center of a region bounded by lines of constant longitude and latitude at integral numbers of degrees or fractions thereof, scaled and interpolated where necessary. The size of the products at highest resolution may require that they be aggregated in subsets of global coverage. Global standard products use the Equirectangular map projection, while the higher-resolution products afforded by dense polar coverage use Polar Stereographic projection. Tiling will be employed to limit the size of individual products to less than 2 GB to facilitate electronic data transfer. Binary elevation data may consist of 16-bit integers scaled by 30.48 cm (assuming a dynamic range of 1728 to 1748 km), or as 32-bit integers scaled to millimeters. The resolution of equirectangular pixels will be powers of two pixels per degree of longitude and latitude. The resolution of polar projected pixels will be integral numbers of meters, scaled by a radius of 1737.4 km. Anticipated tiles and product sizes are as follows, while tiling is shown in Figure 1.

Table 12. Equirectangular map-projected digital elevation models

Product	Product Size	Pixel size	Number/size of tiles	bits per pixel
LDEM_4	4 MByte	7.5808 km in latitude	Global, 0-360	32
LDEM_16	64 MByte	1.895 km in latitude	Global, 0-360	32
LDEM_32	256MByte	0.9476 km in latitude	Global, 0-360	32
LDEM_64	1 GByte	0.4738 km in latitude	Global, 0-360	32
LDEM_128	2 GByte	0.2369 km in latitude	Global, 0-360	16
LDEM_256	4x2GB	118.45 m in latitude	4 tiles, longitudes 0:180:360 by N/S	16
LDEM_512	16x2GB	59.225 m in latitude	16 tiles, longitudes 0:45:90:135:180:225:270:315:360 by N/S	16
LDEM_1024	64x2GB	29.612 m in latitude	64 tiles, longitudes as above, in 22.5° latitude bands	16

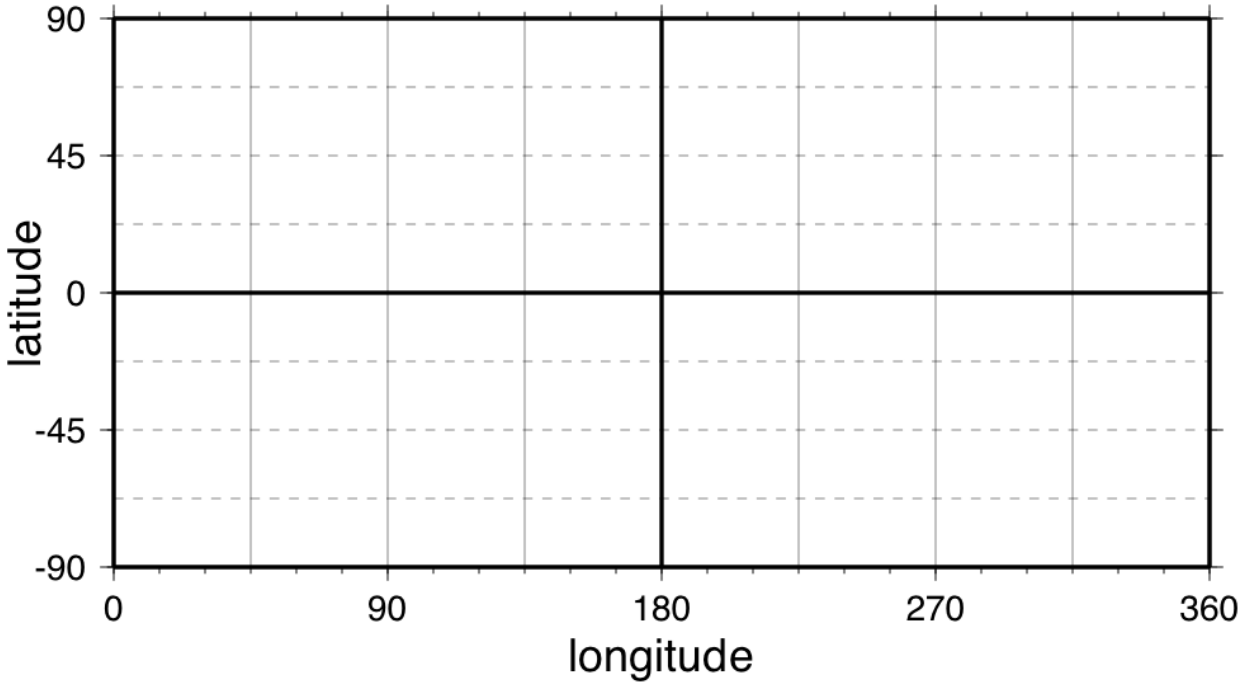

Figure 1: Equirectangular map projection. Lines show tiling subdivisions of LDEM_256 (bold), LDEM_512 (fine), and LDEM_1024 (dashed).

Polar stereographic projections will be produced at latitudes from 45 degrees to the poles. These will have pixel sizes in multiples of meters, true at pole, scaled to a sphere of radius 1737.4 km, and will consist of a single image file at each pole, roughly 1.8 GB in size.

Table 13. Polar map-projected digital elevation models

Product	dimensions	Pixel size	Latitude range	bits per pixel
LDEM_100	28786x28786	100x100m	+/-45° to pole	16
LDEM_60	31036x31036	60x60 m	+/-60° to pole	16
LDEM_30	30496x30496	30x30 m	+/-75° to pole	16
LDEM_20	30400x30400	20x20 m	+/-80° to pole	16
LDEM_10	30342x30342	10x10 m	+/-85° to pole	16
LDEM_5	30328x30328	5x5 m	+/-87.5° to pole	16

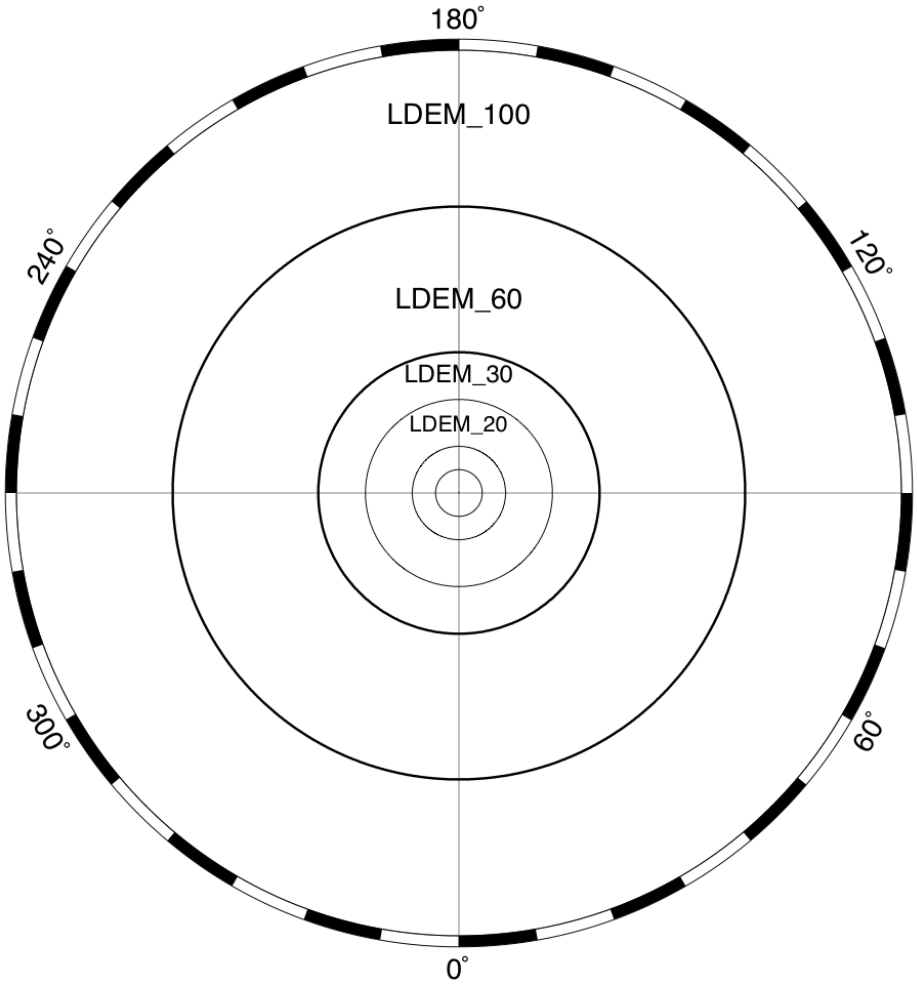

Figure 2: Polar stereographic map projection from 45°N to pole. Circles show outlines of LDEMs at various resolutions (innermost circles enclose 10 and 5 meter DEMs).

Special map products will be generated to describe surface properties such as albedo, slope, and roughness, in formats consisting of a subset of the DEM products. Algorithms for producing these products will depend on performance of the instrument, research and development. Ancillary special map products will be generated to show data density or interpolation quality.

The LOLA SHADR data products consist of ASCII tables, preceded by PDS labels. The form of these tables will be that of Comma-Separated Values. The tables will closely resemble that of the Lunar Prospector gravity archives. Spherical harmonic shape and bidirectional reflectance models will complete the SHADR dataset. The gravity potential coefficients are customarily normalized so that the spherical harmonic functions each have unit mean variance on a sphere, in accordance with geophysical practice, and are further normalized to a reference equatorial radius of 1738000. meters. This choice of radius is for compatibility with legacy datasets, and with observation equations - "normal equations" - used in orbital and potential analysis that, for compact storage, are summed with respect to a particular radius. The derived potential coefficients may be transformed to any other choice of reference radius.

4. Archive Volume Generation

4.1. Data Transfer and Validation Methods

The LOLA EDR and RDR products and labels are generated by the Lunar Orbiter Laser Altimeter Science Team at GSFC. The LOLA Team validates the products for scientific integrity in conjunction with other LRO instrument teams. With rare exceptions, the EDR products are simply checked for transmission errors and correctness of the associated labels, and provided to the Project. The RDR products undergo editing steps and pipeline processing, with subsequent analysis to validate their measurement accuracy. The RDR products will undergo monthly revisions after each orbit maintenance cycle. Standard methods are used to create the GDR and SHADR products, whose revisions are associated with that of the cumulative RDR dataset. The entire archive is hosted at the LOLA SOC as a Data Node of the PDS, per Applicable Document #6. According to the schedule set by the LRO Project, the LOLA Team will make a delivery of completed archive volumes to PDS every three months, beginning six months after the start of the mapping mission. The Geosciences Node validates sample EDR and RDR products and completed archive volumes for compliance with PDS standards. Delivery to PDS will be performed in accordance with Applicable Document #6.

4.2. Data Product Sizes and Delivery Rates

Table 2 summarizes expected sizes and production rates for the LOLA EDR and RDR Standard Products, as well as estimates of the higher level product volumes.

Table 14. Standard Product Sizes and Delivery Rates

Product	Product Size	Production Rate	Expected Number of Products for Primary Mission (366 days)	Expected Total Data Volume for Primary Mission
LOLA_EDR	1 MByte	296 per day, average	108000	108 GB
LOLA_RDR	24 MByte	25-26 per day	9400	225 GB
LOLA_GDR	<2 GByte	monthly revisions of ~100 data products	100	200 GB
LOLA SHADR	5 MByte	release at quarterly intervals	4	<1 GB

4.3. Interface Media Characteristics

All removable volumes in the LOLA Standard Product Archive, whether CD or DVD-ROM media or electronic archive, conform to ISO 9660 standards [ISO 9660, 1988].

4.4. Backup and Duplicates

Backup copies of LOLA EDR, RDR, GDR, and SHADR products will be stored at the LOLA PDS Data Node at GSFC and at the Department of Earth, Atmospheric, and Planetary Sciences

of the Massachusetts Institute of Technology until the final versions of products have been archived on physical media with the PDS. Duplicate copies of LOLA archive volumes will be stored on physical media at the PDS Geosciences Node and the NSSDC.

4.5. Labeling and Identification

There is are two LOLA archive volumes. They will be identified by a unique VOLUME_ID formed according to the scheme LROLOL_dXXX where:

LRO is the mission ID

LOL is the instrument ID

d is the data set stored on the archive volume, where

d = 0 for EDR only;

d = 1 for RDR, GDR, SHADR, and special products.

Should it become necessary to rerelease the archives, the VOLUME_ID will be incremented. XXX represents an online volume of unlimited size. In the event that the PDS ever repackages the archive on smaller media units such as DVDs, the XXX is replaced by a volume sequence number starting with 001.

5. Support Staff and Cognizant Persons

David E. Smith, LOLA Principal Investigator, NASA Goddard Space Flight Center

Maria T. Zuber, LOLA Deputy P.I., Massachusetts Institute of Technology

Gregory A. Neumann, LOLA co-Investigator, NASA Goddard Space Flight Center

Mark H. Torrence, LOLA Science Operations Manager, NASA Goddard Space Flight Center

Susan Slavney, PDS Geosciences Node, Washington University, St. Louis, Missouri

Jennifer G. Ward, Mission Archivist, PDS Geosciences Node, Washington University, St. Louis, Missouri

6. Appendices

6.1. Contents of the INDEX.LBL file

```
PDS_VERSION_ID        = PDS3

RECORD_TYPE           = FIXED_LENGTH
RECORD_BYTES          = 272
FILE_RECORDS          = <number of lines in index, updated>

^INDEX_TABLE          = "INDEX.TAB"

INSTRUMENT_HOST_NAME  = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_NAME       = "LUNAR ORBITER LASER ALTIMETER"
```

```
/* Start Time is the begining of Phase E, and Stop Time  */
/* is the end of LRO Commissioning                       */
START_TIME            = 2008-11-24T09:01:00.000
STOP_TIME             = 2008-12-31T11:47:14.771
PRODUCT_CREATION_TIME = 2008-12-31T15:34:36.0

OBJECT     = INDEX_TABLE
  INDEX_TYPE         = SINGLE
  INTERCHANGE_FORMAT = ASCII
  ROWS               = <same as file_records>
  ROW_BYTES          = 272
  COLUMNS            = 14
  DESCRIPTION        = "
    This table contains the volume index of all data files on
    this volume.

    Each record of this index consists of comma delimited data
    columns folowed by an ASCII carriage-return and line-feed.
    The row bytes value includes not only the lengths of
    the values themselves, but also any quotes, the commas, and
    the row terminating characters (carriage-return,line-feed)."

  OBJECT     = COLUMN
    NAME          = VOLUME_ID
    COLUMN_NUMBER = 1
    START_BYTE    = 2
    BYTES         = 12
    DATA_TYPE     = CHARACTER
    DESCRIPTION   = "The PDS VOLUME_ID: LROLOL_dXXX, where d is
      0 for EDR or 1 for derived data products."
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME          = FILE_SPECIFICATION_NAME
    COLUMN_NUMBER = 2
    START_BYTE    = 17
    BYTES         = 55
    DATA_TYPE     = CHARACTER
    DESCRIPTION   = "Fully qualified name of the data file, relative to
      the volume root directory"
  END_OBJECT = COLUMN
  /* Note that the file specification orginates at the root, so no */
  /* logical volume path name is included.                         */

  OBJECT     = COLUMN
    NAME          = MISSION_PHASE_NAME
    COLUMN_NUMBER = 3
    START_BYTE    = 75
    BYTES         = 14
    DATA_TYPE     = CHARACTER
    DESCRIPTION   = "The mission phase during which the observations
       were obtained. Acceptable values are:
    LAUNCH, EARLY CRUISE, MID CRUISE, LATE CRUISE, LUNAR ORBIT ACQUISITION,
    COMMISSIONING, NOMINAL MISSION, EXTENDED MISSION."
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME          = TARGET_NAME
    COLUMN_NUMBER = 4
    START_BYTE    = 92
    BYTES         = 12
    DATA_TYPE     = CHARACTER
    DESCRIPTION   = "The target observed, e.g., Moon."
```

```
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = PRODUCT_ID
  COLUMN_NUMBER = 5
  START_BYTE    = 107
  BYTES         = 21
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "PRODUCT_ID from the PDS label, e.g.,
    LOLAEDR_083070000_DAT."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = PRODUCT_VERSION_ID
  COLUMN_NUMBER = 6
  START_BYTE    = 131
  BYTES         = 3
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "PRODUCT_VERSION_ID from the PDS label."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = PRODUCT_CREATION_TIME
  COLUMN_NUMBER = 7
  START_BYTE    = 136
  BYTES         = 19
  DATA_TYPE     = TIME
  DESCRIPTION   = "Creation time from the PDS label."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = DATA_SET_ID
  COLUMN_NUMBER = 8
  START_BYTE    = 157
  BYTES         = 23
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "DATA_SET_ID from the PDS label."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = STANDARD_DATA_PRODUCT_ID
  COLUMN_NUMBER = 9
  START_BYTE    = 183
  BYTES         = 10
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "STANDARD_DATA_PRODUCT_ID from the PDS label.
   Identifies the data product in the volume archive, e.g.,
   LOLAEDR."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = START_TIME
  COLUMN_NUMBER = 10
  START_BYTE    = 196
  BYTES         = 19
  DATA_TYPE     = TIME
  DESCRIPTION   = "The UTC START_TIME value from the PDS label."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = STOP_TIME
  COLUMN_NUMBER = 11
  START_BYTE    = 216
```

```
    BYTES          = 19
    DATA_TYPE      = TIME
    DESCRIPTION    = "The UTC STOP_TIME value from the PDS label"
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME           = START_MET_PARTITION
    COLUMN_NUMBER = 12
    START_BYTE     = 236
    BYTES          = 3
    DATA_TYPE      = ASCII_INTEGER
    DESCRIPTION    = "The MET partition (roll-over count) associated with
    the SPACECRAFT_CLOCK_START_COUNT value (column 13). This value is
    incremented by 1 for every instance where MET values have been reset."
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME           = SPACECRAFT_CLOCK_START_COUNT
    COLUMN_NUMBER = 13
    START_BYTE     = 240
    BYTES          = 13
    DATA_TYPE      = ASCII_INTEGER
    DESCRIPTION    = "The SPACECRAFT_CLOCK_START_COUNT value from the PDS
      label. This is the MET of the begining of the observation."
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME           = STOP_MET_PARTITION
    COLUMN_NUMBER = 14
    START_BYTE     = 254
    BYTES          = 3
    DATA_TYPE      = ASCII_INTEGER
    DESCRIPTION    = "The MET partition (roll-over count) associated with
    the SPACECRAFT_CLOCK_STOP_COUNT value (column 15). This value is
    incremented by 1 for every instance where MET values have been reset."
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME           = SPACECRAFT_CLOCK_STOP_COUNT
    COLUMN_NUMBER = 15
    START_BYTE     = 258
    BYTES          = 13
    DATA_TYPE      = ASCII_INTEGER
    DESCRIPTION    = "The SPACECRAFT_CLOCK_STOP_COUNT value from the PDS
      label. This is the MET of the end of the observation."
  END_OBJECT = COLUMN

END_OBJECT = INDEX_TABLE

END
```